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Small-scale passive drift of snail shells on a slope

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Abstract: Using empty shells in malacological-ecological studies on species composition and communities is associated with some benefits in particular to gain much data for statistics with relative ease. In hilly or mountainous areas it can be assumed that empty shells will be found which drifted by passive processes. These could produce statistical biases in the data set and lead further to biased results. In this study I wanted to show that empty shells of terrestrial gastropods can passively drift long distances on a small spatial scale on slopes within a short period of time. Therefore I examined if passive drift of *Cepaea* spp., *Helicella itala* and *Zebrina detrita* on a slope near Jena (Thuringia, Germany) occurs and if significant differences in their drift exist related to their shell shape and the underground. It could be shown that within the short time period of this survey passive drift occured. In dependence on their shape (*Cepaea* spp. = globular, *Helicella itala* = depressed and *Zebrina detrita* = spindle-shaped) *Helicella*-shells are the most effective drifters. Within 39 days empty shells of *Zebrina detrita* are significantly the less effective drifters. An almost significant difference in dependence on the underground (with and without vegetation) exists.

Keywords: terrestrial gastropods, passive drift, empty snail shells, shell shape, small-scale dispersion

Zusammenfassung: Leergehäuse werden häufig als Ergänzung des Datenmaterials malakologisch-ökologischer Studien verwendet, da sie gewisse Vorteile bieten wie z. B. eine hohe Anzahl von Daten für die statistische Auswertung mit relativ geringem Aufwand zu gewinnen. Es kann jedoch angenommen werden, dass an Hängen oder in bergigen Untersuchungsgebieten leere Gehäuse aufgefunden werden, welche aufgrund passiver Prozesse verdriftet wurden. Diese könnten zu statistischen Verzerrungen im Datensatz und damit den Ergebnissen führen. In dieser Studie sollte gezeigt werden, dass Leergehäuse innerhalb kurzer Zeit große Distanzen innerhalb einer kleinräumlichen Skala aufgrund passiver Verdriftung zurücklegen können. Dazu wurde untersucht, ob Verdriftung von *Cepaea* spp., *Helicella itala* und *Zebrina detrita* an einem Berghang nahe Jena (Thüringen, Deutschland) stattfindet und ob signifikante Unterschiede in ihrer Effektivität zur Verdriftung aufgrund ihrer Gehäuseform und dem Untergrund vorliegen. Es konnte gezeigt werden, dass innerhalb eines kurzen Zeitraumes passive Verdriftung stattfindet. In Abhängigkeit der Gehäuseform (*Cepaea* spp. = globulös, *Helicella itala* = flach und *Zebrina detrita* = konisch zulaufend) erwiesen sich leere *Helicella*-Gehäuse als besonders effektive Verdrifter. Leergehäuse von *Zebrina detrita* legten signifikant kürzere Distanzen innerhalb von 39 Tagen zurück. Ein fast signifikanter Unterschied bestand in Abhängigkeit der verdrifteten Distanz zum Untergrund (mit und ohne Vegetation bedeckt).

Introduction

Studies that examine ecological questions about terrestrial gastropods often gain data by collecting both live snails and empty shells as common practice (KERNEY & al. 1983). Some studies include empty shells due to the experimental design (SCHILTHUIZEN 2011), e. g. CLEMENTS & al. (2008) and SCHILTHUIZEN & al. (2002) sampled in their study exclusively empty shells. This approach often relies on the assumption that empty shells are a probabilistic indicator if a given species is abundant in a certain area (THURMAN & al. 2008). Terrestrial snails are most often surveyed in micro-habitats within sites that researchers consider likely to harbor snails (MENEZ 2001, 2007, CAMERON & POKRYSZKO 2005, SÓLYMOS & al. 2009).

Shells of terrestrial mollusks will decay and disappear over time but how long it takes is not well studied yet (SCHILTHUIZEN 2011). It is often assumed that shells persist for a longer time in calcium-rich environments (MILLAR & WAITE 1999). After PEARCE (2008) it is also known that the respective species have an effect on the decomposition rate, e. g. larger shelled species decompose slower than small shelled ones.

Collecting empty shells has several advantages, in particular as it is independent of the species' activity periods (SÓLYMOS & al. 2009). Moreover, empty shells are easy to collect also for untrained searchers, in particular with hand-picking macro species (larger than 5 mm) compared to micro species (smaller than 5 mm). But also with substrate samples a large number of individuals of micro species are easy to collect. In this way, vast amounts of data can be obtained – a good starting point for subsequent statistical analyses.

However, in some environments (like mountainous areas, slopes, rivers and glaciers) which are characterized by periodic strong water movements, e. g. after a rainy storm or melting of snow – empty shells could passively drift away from the place individuals died and be transported downstream with water over long distances (SMITH 1966, HUBER & al. 1997, KNORRE 2011). Biotic activities are another reason for biased accumulations of empty shells like the commonly known thrush anvils (ANTON & BOSSDORF 2009) and the yet cryptic and less studied accumulation of shells at ant hills (PÁLL-GERGELY & SÓLYMOS 2009). Already BAUR & al. (1997) showed that even in similar species like *Arianta arbustorum* (LINNAEUS 1758) and *A. chamaeleon* (PFEIFFER 1868) drift efficiency could be associated with the size and shape of the respective shells.

Shell morphology per se is well studied within many terrestrial snail species mostly with focus on their evolution and genetics (CHO & al. 2006), but not on their ability for drifting passively. Conducting a small-scale experiment the goal of this paper is to examine the passive drift of empty shells of four terrestrial gastropod species (*Cepaea hortensis* (O. F. MÜLLER 1774), *C. nemoralis* (LINNAEUS 1758), *Helicella itala* (LINNAEUS 1758) and *Zebrina detrita* (O. F. MÜLLER 1774)) and to which extend and in what time they drift. I examined shells of three different shapes to see if there are differences in the distance they passively drifted during 39 days. In addition, I tested if there are differences in passive drifting depending on the underground if it is covered with vegetation or consists of bare rocks without vegetation.

Methods

Study area and weather conditions

The study was conducted in the "Leutratal und Cospoth" nature reserve near Jena (Thuringia, Germany) on a slope of the Jagdberg, which is part of a landscape characterized by calcareous grassland along slopes formed by the Saale River (PFEIFER & al. 2006). The south-exposed slope can be described as an extreme habitat because of the calcareous soil with low water storage capacity, the high heating in summer (up to 70 °C on the soil layer) and therefore the related drought (HEINRICH & MARSTALLER 1998). Climatic conditions are characterized by mild winters with few periods of frost (KLUGE & MÜLLER-WESTERMEIER 2000). The average annual temperature in 1991-2000 was 9.9 °C and mean precipitation 612 mm. The average wind velocity near the ground on the slopes of the Leutratal is 2 m/s which is relatively high compared with the surrounding area (under 1.5 m/s) and can be explained by the high inclination of the slopes and down-slope winds (HOFFMANN & al. 2014). The study was done end of March until the beginning of May 2015 during a period of moderate weather conditions, e. g. approximately 30 mm precipitation and circa 8 °C (TLUG Jena 2016).

Shell preparation

For this study I searched for empty shells of four snail species which would fit into arbitrary chosen categories of shapes of those shells. Categories were considered as globular, depressed and spindle-shaped. Based on the rough number of abundant snails in the study area I decided to use shells of *Cepaea* spp. (Helicidae) as representatives for the category "globular", shells of *Helicella itala* (Hygromiidae) for the category "depressed" and *Zebrina detrita* (Enidae) as "spindle-shaped". All these species live in mountainous areas in central Europe (KERNEY & al. 1983). I used 40 empty shells of each species for the experiment, i. e. 120 empty shells in total (*Cepaea hortensis* and *C. nemoralis* together as one species group). Shell size was comparatively from similar size. Width / height were for all *Cepaea* specimens 2.1 cm ± 0.2 cm / 1.7 cm ± 0.2 cm, for *Helicella* 1.5 cm ± 0.1 cm / 0.6 cm ± 0.1 cm and for *Zebrina* 0.9 cm ± 0.1 cm / 2.2 cm ± 0.1 cm.

The outer surfaces of the shells were cleaned with a toothbrush and water. Shells were marked with conspicuous nail varnish for easy retrieval (e. g. FENWICK & AMIN 1983, GOSSELIN 1993, HENRY & JARNE 2007). In addition a sealer was applied on the nail varnish to minimize environmental-related bleach out of the tag.

Fig. 1: Study area with an approximated inclination of 32°. In the foreground: plots with stony underground, in the background: the village Maua near Jena (photo: M. KRÜGER).

Experimental design

The places of the plots with specific underground were randomly chosen on calcareous south-exposed slopes and had an average inclination of approximately 32°. Twenty shells of each shape type were put on bare rocks and on an underground with typical xerothermic vegetation (*Teucrio-Seslerietum*). The starting line on the slope was marked with white yarn (width one meter) attached on two wooden sticks. Observations were conducted for 39 days with measurements in the first week every second day, later every forth day. I measured the distance the shells drifted from the starting line using a common folding meter stick. During the whole survey only one person measured the distance the shells passively drifted to reduce person-related errors.

Statistics

For the shell size of the individuals and the drifted distance without eliminating outliers I used standard descriptive statistic methods like calculating the mean values and standard deviation.

Drift-data were $\log_{10}$-transformed after calculating the mean values of each drifted shell to reduce effects of large numbers, in particular far drifted shells compared to short distance drifted ones. Log_{10}-transformation was also needed to fulfil the assumptions of parametric tests (linear relationship, normal distribution). The data treatment comprised also the elimination of outliers and check for normal distribution via a Shapiro-Wilk normality test. With a Fligner-Killeen test I checked for homogeneity of variance to fulfil all requirements needed for a two-way analysis of variance (CRAWLEY 2007). The relations between shapes of shells, the distance drifted and between shell shapes and underground (with and without vegetation) were compared with a two-way analysis of variance (ANOVA). The primary test was followed by a Tukey test to check for pairwise differences between the three different shapes. All statistics were performed using the free software R (Version 0.98.1102).

Results

Without eliminating outliers *Cepaea* specimens drifted on vegetation plots approximately 3.4 cm (± 3.3 cm) in one month, on bare rocks 12.5 cm (± 17.2 cm), whereas the drifted distance of *Helicella itala* individuals was on vegetation plots 3.2 cm (± 3.1 cm) and on bare rocks 7.9 cm (± 7.4 cm). Individuals of *Zebrina detrita* drifted 2.3 cm (± 2.0 cm) on vegetation plots and on plots with bare rocks 3.7 cm (± 6.2 cm).

In general the underground had an almost significant impact on the distance: all empty shells drifted passively ($F_{1, 109} = 3.688$, $p = 0.057$; Fig. 2) after eliminating outliers. With respect to the different shell shapes the impact of underground on spindle-shaped shells ($F_{1, 37} = 0.1912$, $p = 0.664$; Fig. 3a) and globular shells ($F_{1, 38} = 0.0145$, $p = 0.905$; Fig. 3b) was non-significant but highly significant for depressed shells ($F_{1, 37} = 7.4862$, $p = 0.009$; Fig. 3c).

In total, the shape of empty shells had a highly significant impact ($F_{2, 109} = 5.006$, $p = 0.008$; Fig. 4) on the distance drifted. The Tukey test indicates that no significant difference exists between globular and depressed shells ($p = 0.377$) and this also applies to globular and spindle-shaped shells ($p = 0.198$). However a highly significant difference exists between depressed and spindle-shaped shells ($p = 0.005$).

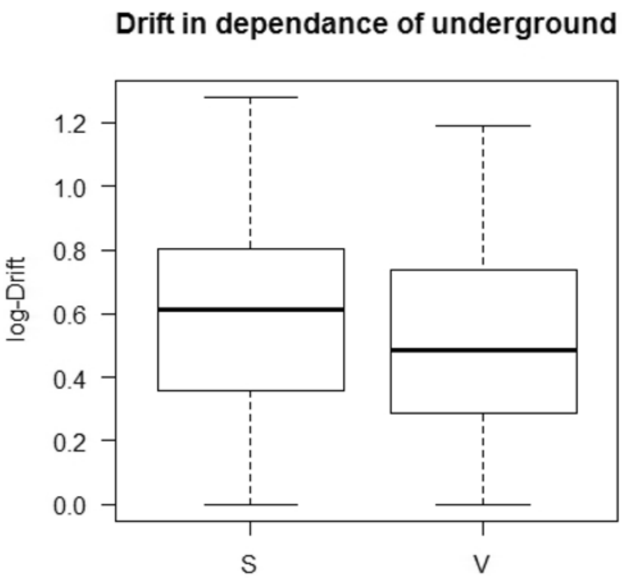

Fig. 2: Boxplot after ANOVA with logarithmized values of drifted distance of all shells after 39 days for S-Plots (with stony underground) and V-Plots (with vegetation).

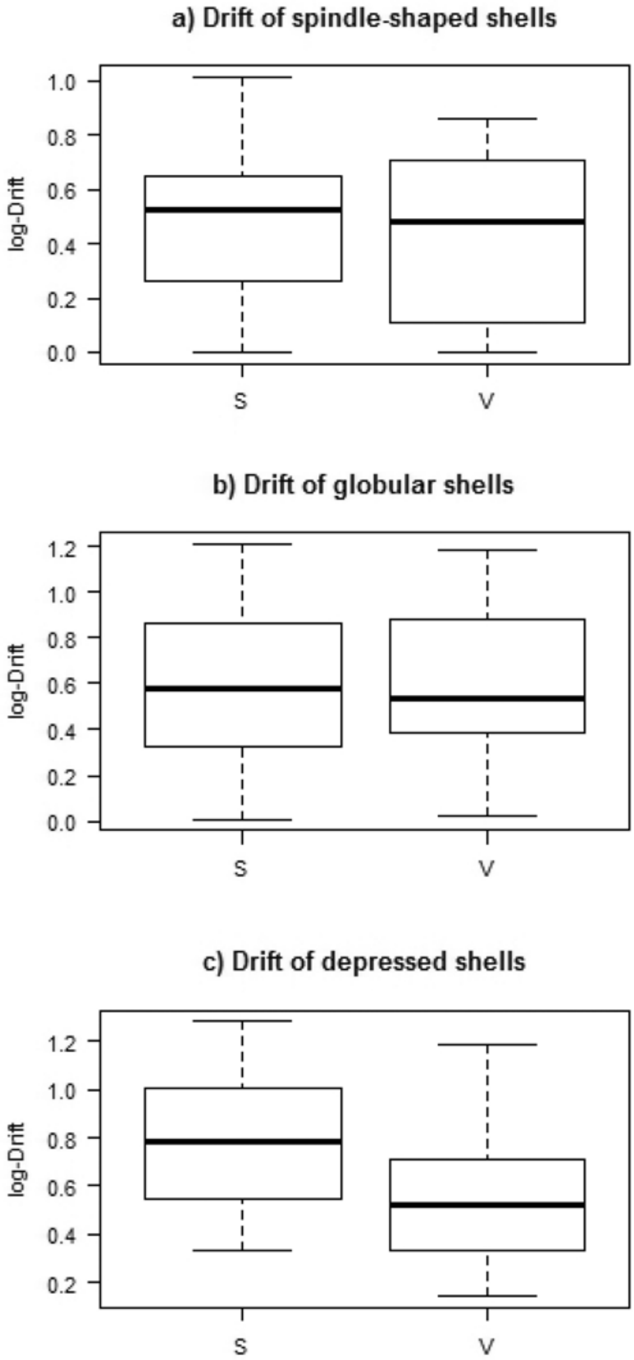

Fig. 3: Boxplots after ANOVA with logarithmized values of drifted distance of shells after 39 days for a) spindle-shaped shells, b) globular shells and c) depressed shells according to S-Plots (with stony underground) and V-Plots (with vegetation).

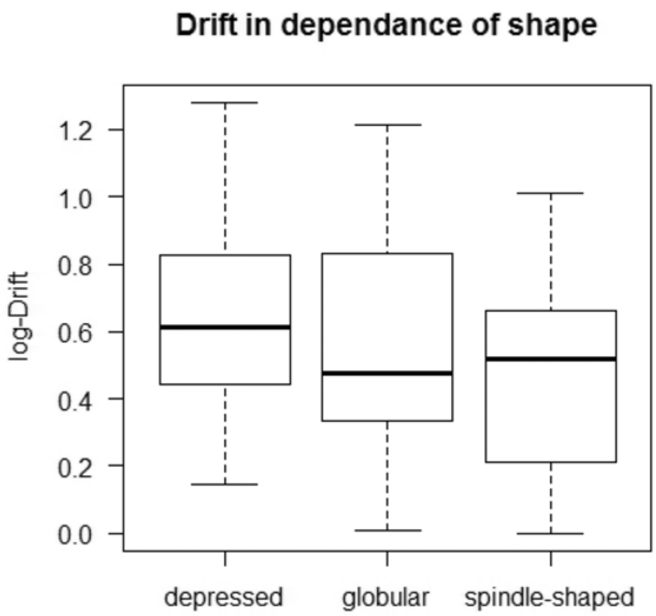

Fig. 4: Boxplot after ANOVA with logarithmized values of drifted distance of shells after 39 days according to the three categories depressed, spindle-shaped and globular.

Discussion

The trend for faster drift on bare rocks is probably linked to the fact that shells are more exposed to wind and down streaming water during stormy weather. In particular on the south-exposed slopes of the nature reserve "Leutratal und Cospoth" high wind velocities from down-slope winds with an average of 2 m/s are common (HOFFMANN & al. 2014). HERRMANN (1990) observed high accumulations of empty shells close together. He assumed that the shells were drifted by flow of water and were then accumulated over time. Moreover HUBER & al. (1997) mentioned that shell accumulations occur probably due to wind and rain.

But one also should take physics as simplest solution into account, i. e. that on rough surfaces versus rather smooth surfaces shells would drift slower. Even if in total the difference between plots with vegetation and without were only close to be statistically significant vegetation seems to stop downward rolling shells (Fig. 2). BAUR & al. (1997) confirmed that in most cases vegetation structure lead in most cases to stopping of downhill rolling shells.

Zebrina detrita was significantly the less effective drifter in this study. That is interesting with respect to its ecology because this species lives almost exclusively on slopes with moderate to high inclinations whereas the other two species live on a wider range of horizontal and vertical habitats (KERNEY & al. 1983). As an effect of the shape *Zebrina*-shells seem to drift in small circles comparable to the conical eggs of cliff-breeding birds.

Globular shells are not as effective drifters as depressed shells. It might be that the shells are heavier compared to depressed shells or the air resistance of this shape is lower compared to *H. itala* as the more effective drifter in this study. A recent study by the NASA (National Aeronautics and Space Administration) showed that depressed-shaped objects have a higher drag coefficient (a number to model complex dependencies of air resistance on shape, inclination and flow conditions of wind or water streams) than globular-shaped objects (HALL 2015). Her results also indicate the least air resistance for conic-shaped objects. These results corroborate my findings about the drift distances of depressed, globular and spindle-shaped (conical) shells but with certainty more research is needed to check for direct and indirect effects of air resistance, inclination and flow conditions of different shapes of shells.

In conclusion, this study might be one of just a few which examine the small-scale passive drifting of empty shells of terrestrial gastropods. As the number of studies in snail community research and species composition within gastropods increases, this study may provide a useful contribution to a better study design in hilly areas and so a more realistic approach to the ecology of snails.

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Literature

ANTON, C. & BOSSDORF, O. (2009): Evolution Megalab: Die geheimnisvolle Vielfalt der Bänderschnecken. — Biologie in unserer Zeit, **39**: 14–15, Weinheim.

BAUR, B., LEDERGERBER, S. & KOTHBAUER, H. (1997): Passive dispersal on mountain slopes: Shell shape-related differences in downhill rolling in the land snails *Arianta arbustorum* and *A. chamaeleon* (Helicidae). — Veliger, **40**: 84–85, Berkeley.

CAMERON, R. A. D. & POKRYSZKO, M. (2005): Estimating the species richness and composition of land mollusc communities: problems, consequences and practical advice. — Journal of Conchology, **38**: 529–547, London.

CHO, M. S., YAP, C. K., TAN, S. G. & JAMBARI, H. A. (2006): Morphological and allozyme studies of small terrestrial snails (*Opeas* sp., *Subulina* sp. and *Huttonella bicolor*) collected from Peninsular Malaysia. — Genetika, **42**: 49–57, Moskau.

CLEMENTS, R., LU, X. X., AMBU, S., SCHILTHUIZEN, M. & BRADSHAW, C. (2008): Using biogeographical patterns of endemic land snails to improve conservation planning for limestone karsts. — Biological Conservation, **141**: 2751–2764, Oxford.

CRAWLEY, M. J. (2007): The R Book. — 950 pp., London (John Wiley and Sons).

FENWICK, A. & AMIN, M. A. (1983): Marking snails with nail varnish as a field experimental technique. — Annals of Tropical Medicine and Parasitology, **77**: 387–390, Liverpool.

GOSSELIN, L. A. (1993): A method for marking small juvenile gastropods. — Journal of Marine Biological Association of the UK, **73**: 963-966, Cambridge.

HALL, N. (2015): Shape Effects on Drags, Glenn Research Center, NASA (National Aeronautics and Space Administration). — online *www.grc.nasa.gov/www/K-12/airplane/shaped.html* [updated in May 2015, accessed 26.09.2015]

HEINRICH, W. & MARSTALLER, R. (1998): Naturräumliche Verhältnisse des Leutratals. — Naturschutzreport, **14**: 14–21, Jena.

HENRY, P. Y. & JARNE, P. (2007): Marking hard-shelled gastropods: tag loss, impact on life-history traits, and perspectives in biology. — Invertebrate Biology, **126**: 138–153, Oxford.

HOFFMANN, K., BIVOUR, W., FRÜH, B., KOSSMANN, M., VOSS, P.-H. (2014): Klimauntersuchungen in Jena für die Anpassung an den Klimawandel und seine erwarteten Folgen : ein Ergebnisbericht. — Berichte des Deutschen Wetterdienstes, Bd. **243**, 1-180, Offenbach (Deutscher Wetterdienst).

HUBER, D., VOIGT, W. & ROCHER, C. (1997): Artenkomposition und Populationsdichten der Gastropodenfauna als Indikator für die Umweltbedingungen in Trespen-Halbtrockenrasen – ein Ansatz. — Beiträge zur Ökologie, **3**: 29–40, Jena.

KERNEY, M. P., CAMERON, R. A. D. & JUNGBLUTH, J. H. (1983): Die Landschnecken Nord- und Mitteleuropas. — 384 S., Hamburg, Berlin (Parey).

KLUGE, G. & MÜLLER-WESTERMEIER, G. (2000): Das Klima ausgewählter Orte der Bundesrepublik Deutschland: Jena. — Berichte des Deutschen Wetterdienstes, **213:** 1-304, Offenbach (Deutscher Wetterdienst).

KNORRE, D. V. (2011): Mollusca. Weichtiere. — In: BÄHRMANN, R. (Hrsg.): Bestimmung wirbelloser Tiere (6. Auflage). — 361 S., Heidelberg (Spektrum Akademischer Verlag).

MENEZ, A. (2001): Assessment of land snail sampling efficacy in three Mediterranean habitat types. — Journal of Conchology, **37**: 171–175, London.

MENEZ, A. (2007): A new approach to studying and sampling land molluscs: habitat structure and the effects of scale on land molluscs. — Journal of Conchology, **39**: 321–327, London.

MILLAR, A. J. & WAITE, S. (1999): Molluscs in coppice woodland. — Journal of Conchology, **36**: 25–48, London.

PÁLL-GERGELY, B. & SÓLYMOS, P. (2009): Ants as shell collectors: notes on land snail shells around ant nests. — Malacologica Bohemoslovaca, **8**: 14–18, Bratislava.

PEARCE, T. A. (2008): When a snail dies in the forest, how long will the shell persist? Effect of dissolution and micro-bioerosion. — American Malacological Bulletin, **26**: 111–117, Hattiesburg.

PFEIFER, M., HEINRICH, W. & JETSCHKE, G. (2006): Climate, size and flowering history determine flowering pattern of an orchid. — Botanical Journal of the Linnean Society, **151**: 511–526, London.

SCHILTHUIZEN, M. (2011): Community ecology of tropical forest snails: 30 years after SOLEM. — Contributions to Zoology, **80**: 1–15, Leiden.

SCHILTHUIZEN, M., TERÄVÄINEN, M. I. F., TAWITH, N. F. K., IBRAHIM, H., CHEA, S. M., CHUAN, C. P., DAIM, L. J., JUBAIDI, A., MADJAPUNI, M. J., SABEKI, M. & MOKHTAR, A. (2002): Microsnails at microscales in Borneo: distributions of Prosobranchia versus Pulmonata. — Journal of Molluscan Studies, **68**: 259–262, Oxford.

SMITH, A. G. (1966): Land Snails of the Galápagos. — In: BOWMAN, R. I. (ed.): The Galápagos: Proceedings of the Symposia of the Galápagos International Scientific Project. — 336 pp., London (Cambridge University Press).

SÓLYMOS, P., KEMENCEI, Z., PÁLL-GERGELY, B., FARKAS, R., VILISICS, F. & HORNUNG, E. (2009): Does shell accumulation matter in micro-scale land snail surveys? — Malacologia, **51**: 389–393, Ann Arbor.

Thüringer Landesanstalt für Umwelt und Geologie Jena (TLUG) (2016): Monatliche Temperatur und Niederschlag 2015. Übersichtsposter der Thüringer Landesanstalt für Umwelt und Geologie Jena — online *http://www.thueringen.de/th8/klimaagentur/klima/messstation/index.aspx* [accessed 05.04.2016].

THURMAN, C. F., SHACKLETON, L. P. & HASKELL, D. G. (2008): Does the density of dead shells predict the density of living *Anguispira cumberlandiana* LEA 1840 (Gastropoda: Discidae)? — American Midland Naturalist, **159**: 478–481, Notre Dame.

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